Aerodynamic optimization using Adjoint methods and parametric CAD models

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European Commission

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Motivation

- Perform high-fidelity aerodynamic optimisation

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- Increase flexibility of Adjoint Based Optimisation

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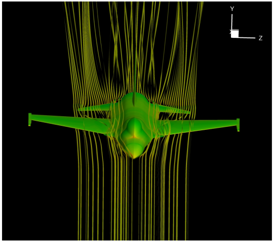
- Perform high-fidelity aerodynamic optimisation
- Increase flexibility of Adjoint Based Optimisation
- Enable use of parametric CAD model in optimisation
- Efficient calculation of parametric sensitivities for CAD based design variables

Motivation

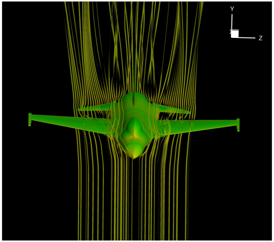
There are two main challenges to perform high-fidelity aerodynamic optimisation



Motivation

There are two main challenges to perform high-fidelity aerodynamic optimisation

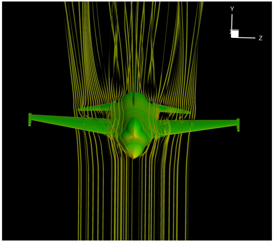
- Computational Cost
  - Gradient Based Optimisation



Motivation

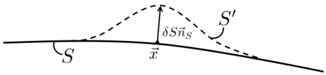
There are two main challenges to perform high-fidelity aerodynamic optimisation

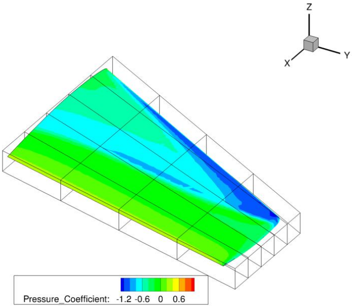
- Computational Cost
  - Gradient Based Optimisation
- Large number of parameters
  - Adjoint Methods



Motivation

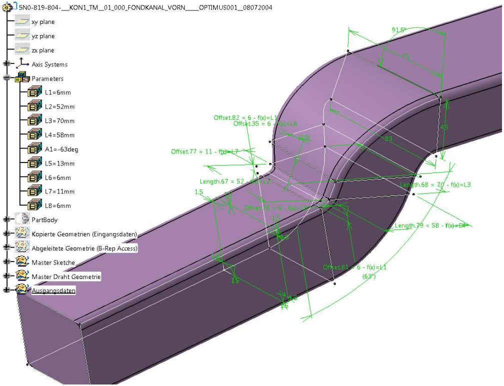
In CFD based optimisation, parameterisations are usual built in the software





Motivation

The objective of this work is to integrate parameters used by CAD designers with high-fidelity analysis and optimisation.

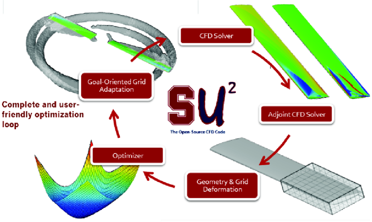


Outline

SU^2

SU^2 is an open-source CFD/Adjoint optimisation framework[1]

- Developed at Stanford University



SU2
The Open-Source CFD Code

[1] images taken from *http://su2.stanford.edu/*

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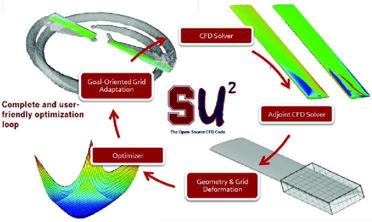

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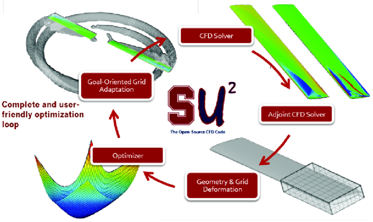
- Range of numerical schemes available (JST, ROE, MG, Euler-Implicit,...)



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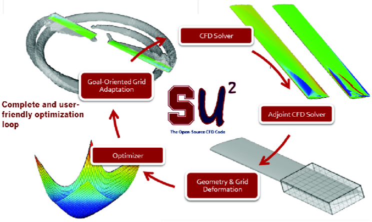

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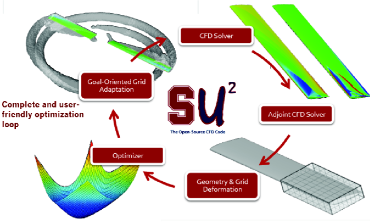

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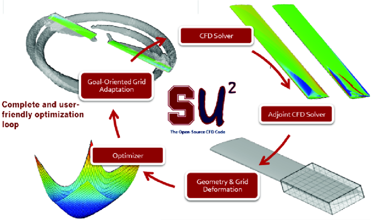
- Independent Mesh deformation/adaptation modules
- Continuous Adjoint Solver
- Independent Gradient Calculation module



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Gradient Based Optimisation

Gradient Calculation

$$\underbrace{\begin{bmatrix} \frac{\partial f}{\partial A_1} \\ \frac{\partial f}{\partial A_2} \\ \vdots \\ \frac{\partial f}{\partial A_n} \end{bmatrix}}_{Gradients} = \underbrace{\begin{bmatrix} \frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_n} \end{bmatrix}}_{Design\ \ Velocities} \underbrace{\begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_m} \end{bmatrix}}_{Surface\ \ Sensitivities}$$

- $\frac{\partial f}{\partial A_i}$ - Gradient
- $\frac{\partial x_j}{\partial A_i}$ - Design Velocities
- $\frac{\partial f}{\partial x_j}$ - Surface Sensitivities

Gradient Based Optimisation

Gradient Calculation

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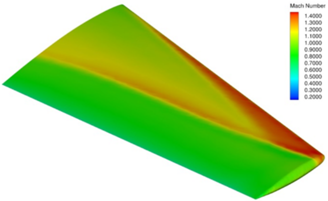
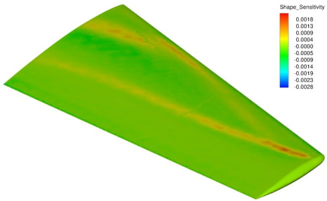
Surface Sensitivities

Flow sensitivity to surface obtained from adjoint solver (SU^2)



FLOW SOLUTION



ADJOINT SOLUTION

Design Velocities

Gradient Calculation

$$\underbrace{\begin{bmatrix} \frac{\partial f}{\partial A_1} \\ \frac{\partial f}{\partial A_2} \\ \vdots \\ \frac{\partial f}{\partial A_n} \end{bmatrix}}_{Gradients} = \underbrace{\begin{bmatrix} \frac{\partial x_1}{\partial A_1} & \cdots & \frac{\partial x_m}{\partial A_1} \\ \vdots & \ddots & \vdots \\ \frac{\partial x_1}{\partial A_n} & \cdots & \frac{\partial x_m}{\partial A_m} \end{bmatrix}}_{Design\ Velocities} \underbrace{\begin{bmatrix} \frac{\partial f}{\partial x_1} \\ \frac{\partial f}{\partial x_2} \\ \vdots \\ \frac{\partial f}{\partial x_m} \end{bmatrix}}_{Surface\ Sensitivities}$$

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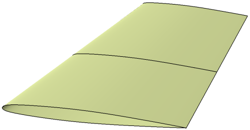
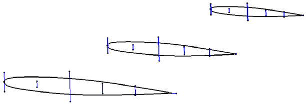
- $\frac{\partial x_j}{\partial A_i}$ - Design Velocities
- $\frac{\partial f}{\partial x_j}$ - Surface Sensitivities

CAD parameterisation

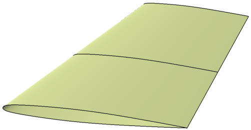


CATIA geometry



27 CATIA Parameters

CAD parameterisation



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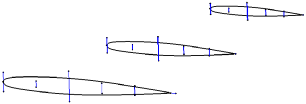

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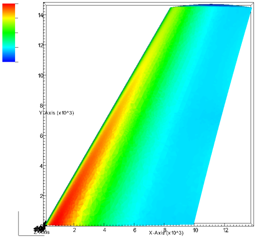
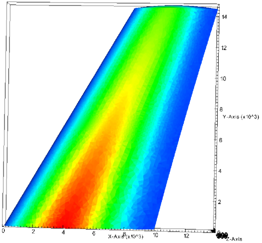
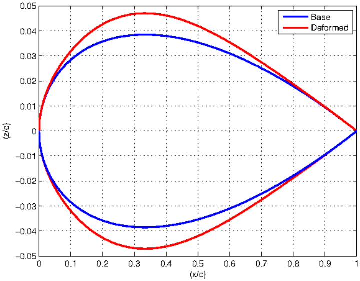


Design Velocities Param.1



Design Velocities to Param.3

Deform Surface

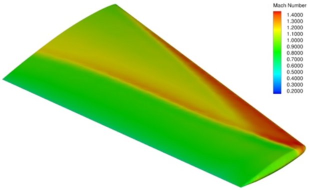


Use design velocities and mesh deformation module (linear elasticity) to deform surface CFD mesh.

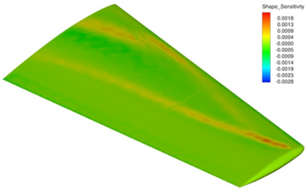
Outline

Flow and Adjoint Solutions

Start the process by computing the flow and adjoint solution



FLOW SOLUTION



ADJOINT SOLUTION

Flow and Adjoint Solutions

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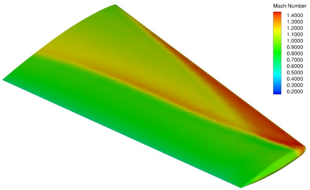
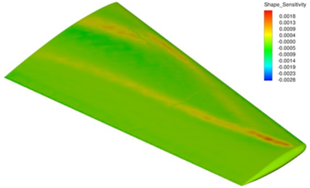


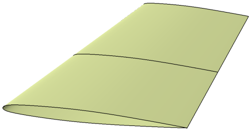
FLOW SOLUTION



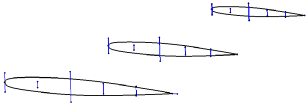
ADJOINT SOLUTION

and at the same time .....

Geometric Sensitivities



CATIA geometry



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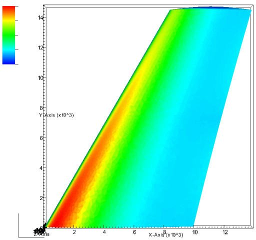
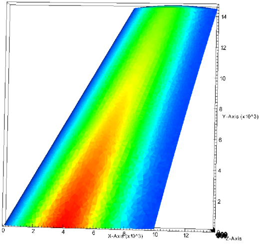


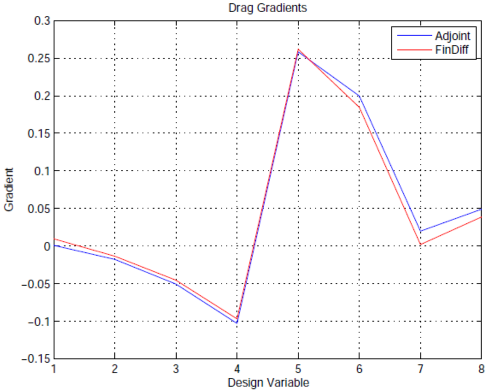
Geometry Sensitivity to Param.1



Geometry Sensitivity to Param.3

Gradient Validation

Compute gradient for optimiser:



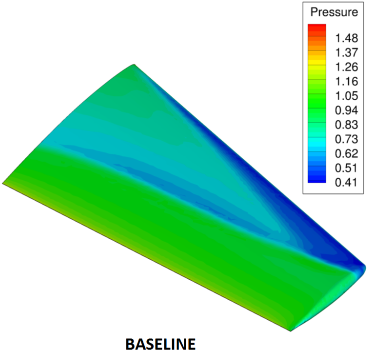
Optimiser returns updated parameter values, which is used to create new CAD model and new design velocities calculated ...

Onera Wing Drag Minimization

Transonic Test Case – Inviscid Calculation

$M_\infty = 0.8395; \alpha = 3.06^\circ$

$$\begin{aligned} &\textit{min } C_D \\ \text{subject to:} \quad & C_L \quad > 0.283 \end{aligned}$$



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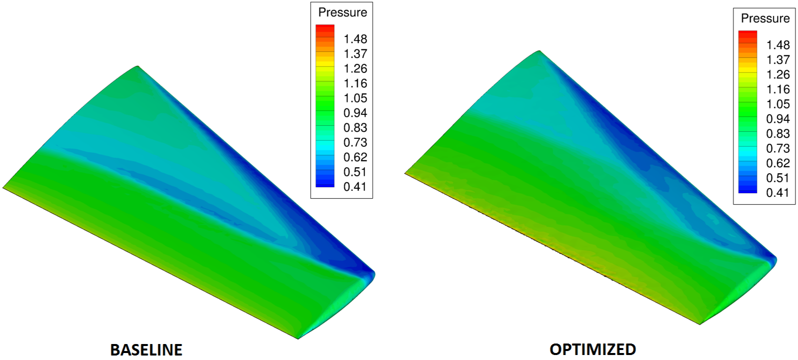

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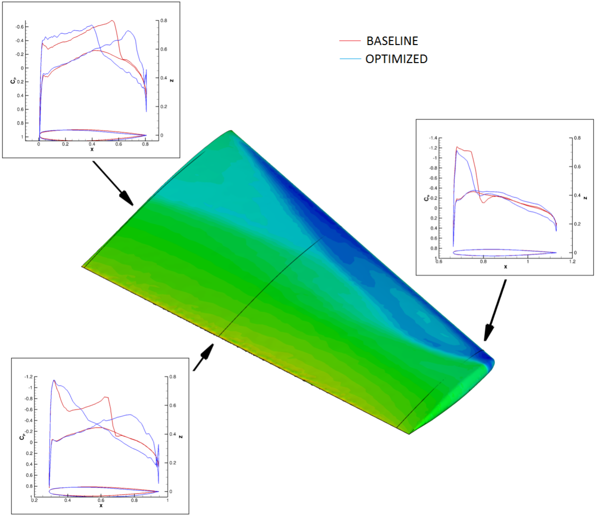

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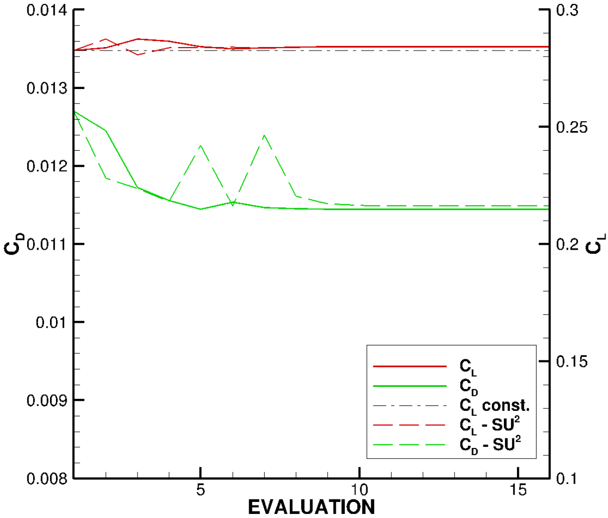
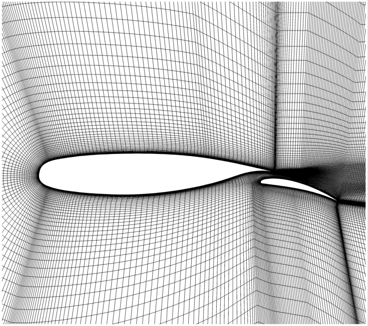
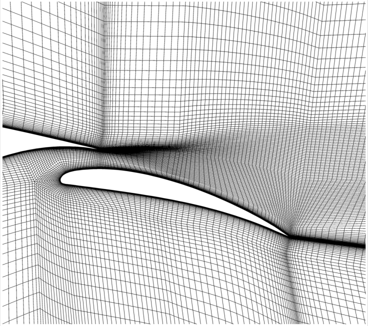


Outline

NLR 7301 High-Lift Case

High-Lift Test Case – RANS Calculation (using SA)
$M_\infty = 0.185; \alpha = 6^\circ; Re = 2.51 \times 10^6;$
Maximise L/D





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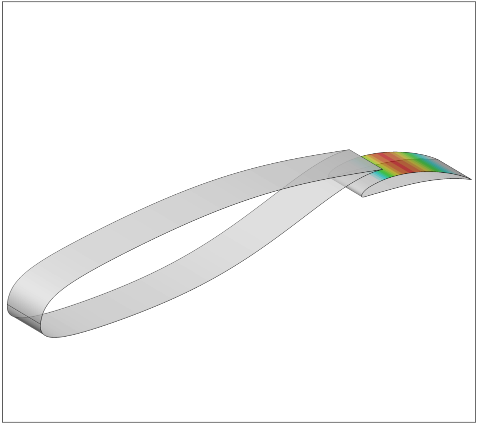

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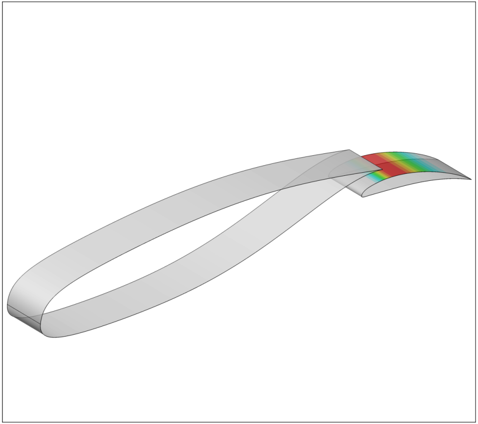

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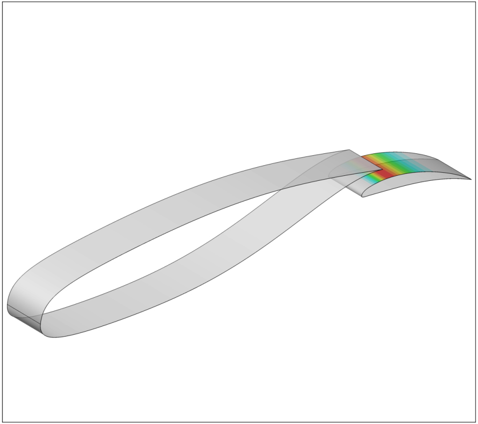

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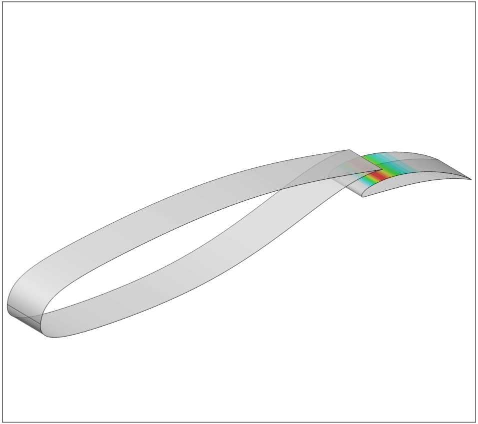

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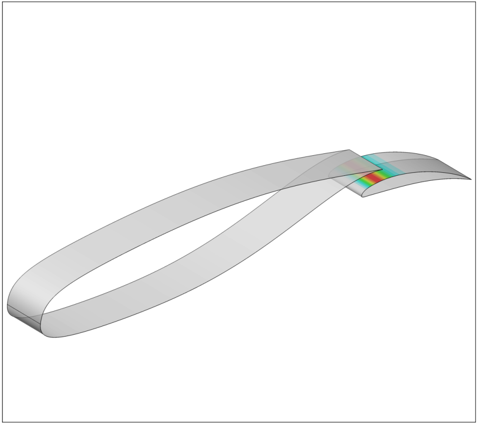

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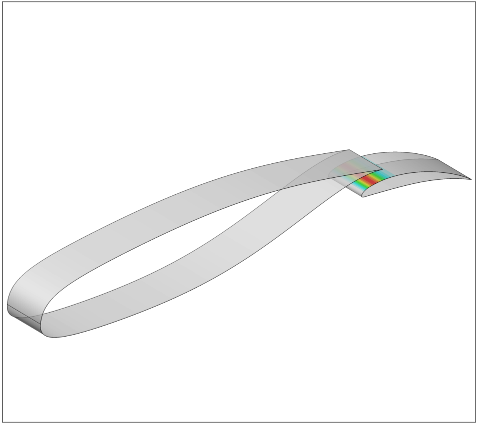

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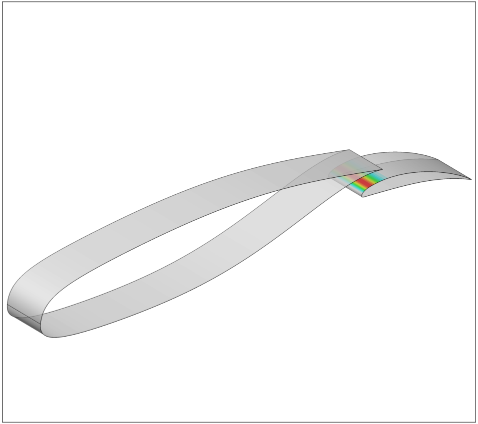

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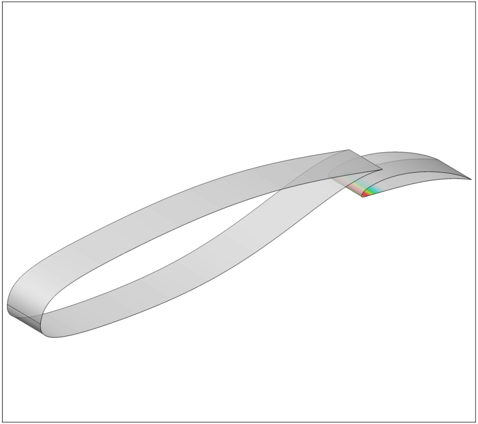

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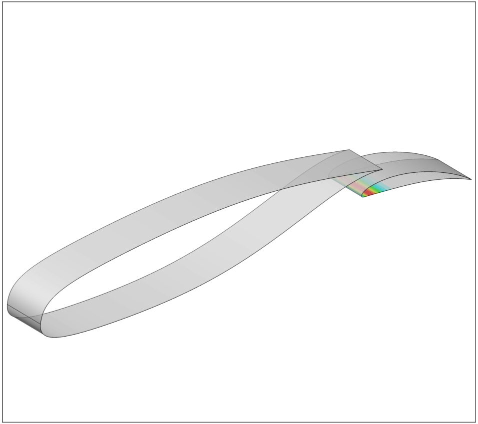

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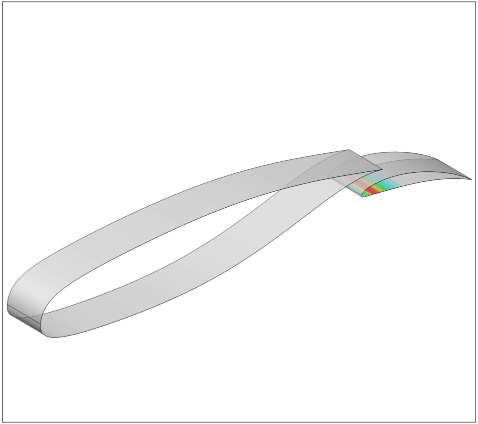

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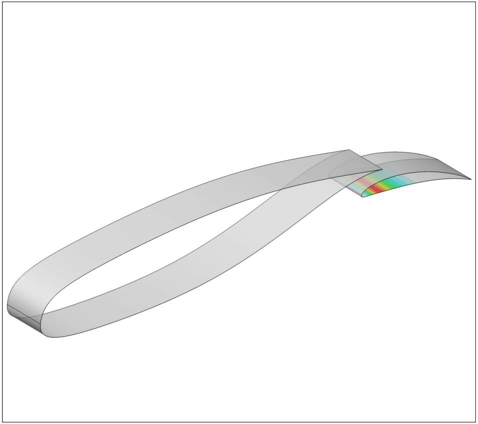

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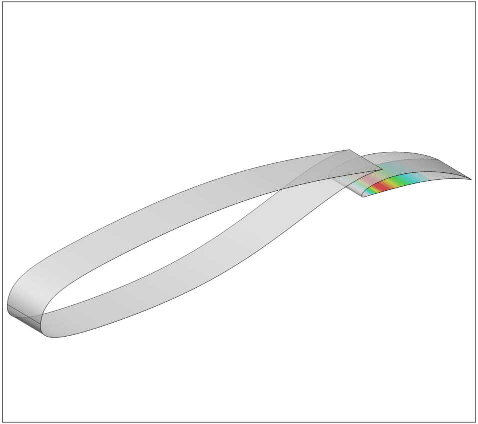

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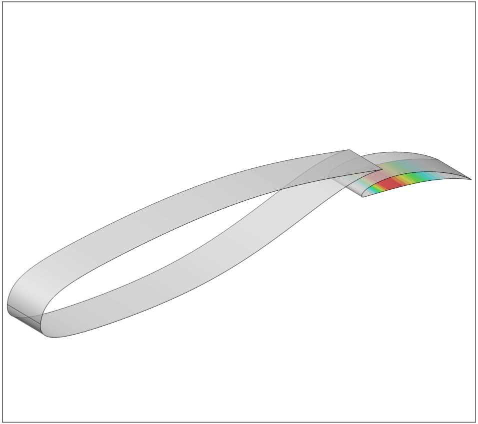
$M_\infty = 0.185; \alpha = 6^\circ$; $Re = 2.51 \times 10^6$;
Maximise L/D; 14 CATIA Parameters



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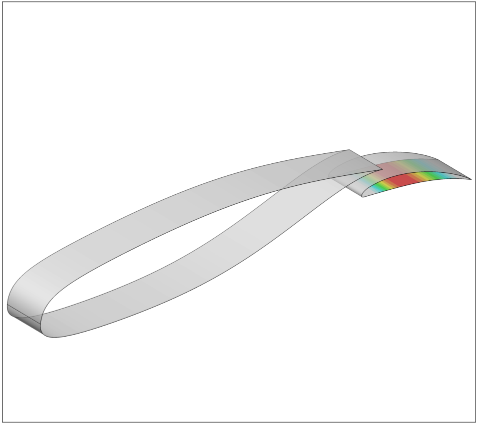

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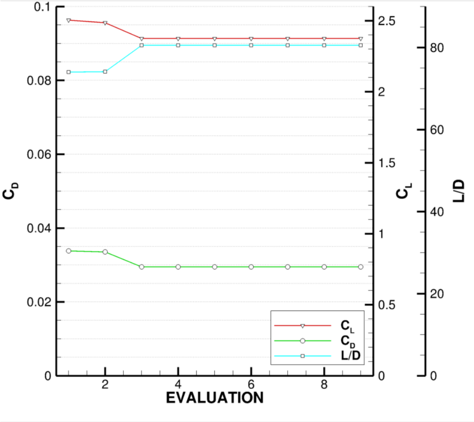

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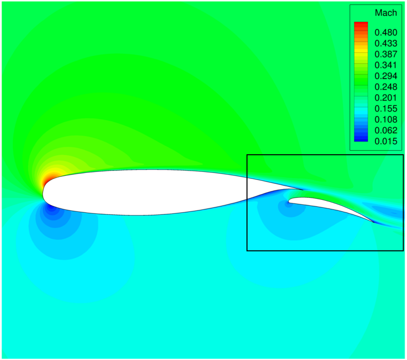
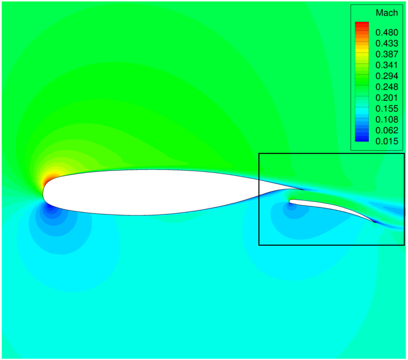


Original



Optimised

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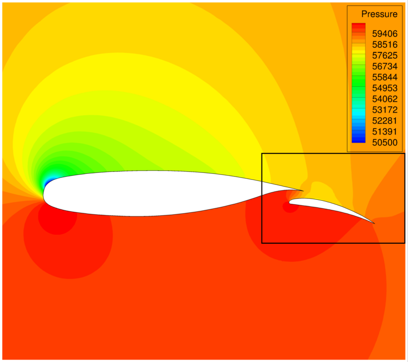

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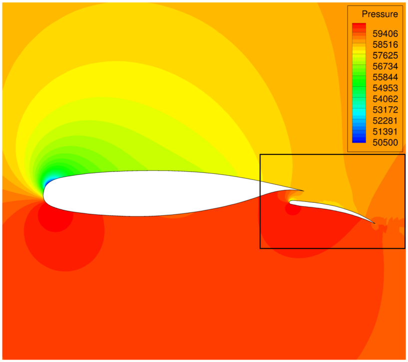

Optimised

Outline

Conclusions

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- Model deformation and geometric sensitivities are calculated outside CFD solver
- Alternative approach does not compromise optimisation efficiency with respect to native parameterisations

Q & A

Thank you for your attention

Questions Welcome